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Comparative study of the sources of exergy destruction on four North Sea oil and gas platforms

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Abstract:

In this paper, the oil and gas processing systems on four North Sea offshore platforms are reported and discussed. Sources of exergy destruction are identified and the findings for the different platforms are compared. Different platforms have different working conditions, such as reservoir temperatures and pressures, gas- and water-to-oil ratios in the feed, crude oil properties, product specifications and recovery strategies. These differences imply that some platforms naturally need less power for oil and gas processing than others. Reservoir properties and composition also vary over the lifetime of an oil field, and to maintain the efficiency of an offshore platform is therefore challenging. In practice, variations in the process feed result in the use of control strategies such as anti-surge recycling, which cause additional power consumption and exergy destruction. For all four platforms, more than 27% of the total exergy destruction takes place in the gas treatment section while at least 16% occurs in the production manifold systems. The exact potential for energy savings and for enhancing system performances differ across offshore platforms. However, the results indicate that the largest potential for improvement lie (i) in gas compression systems where large amounts of gas are often compressed and might be recycled to prevent surge, and (ii) in production manifolds where well-streams are depressurised and mixed before being sent to the separation system.

Keywords:

Exergy destruction, oil and gas processing, energy-intensive techniques, thermodynamic efficiency

1. Introduction

Oil and gas processing on North Sea offshore platforms consume substantial amounts of power and have a significant environmental impact, being responsible for about 26% of the total CO_2 emissions of Norway in 2011 [1]. Onsite processes on offshore facilities suffer from significant performance losses over the lifetime of the installation, as a consequence of substantial variations of the reservoir properties (e.g. pressure and temperature) and of the production flow rates and composition changes (e.g. gas- and water-to-oil ratios, crude oil properties). These off-design conditions lead to the use of control strategies such as anti-surge recycling, and thus to greater power consumption and larger exergy destruction. Moreover, as the oil production decreases with time, energy-intensive techniques such as gas and water injection are employed to enhance oil recovery from the reservoir. It is therefore challenging to maintain a high performance of the overall system over time, while optimising the oil and gas production.

Svalheim and King [2,3] stressed the large power demand of the gas compression and water injection processes over the lifespan of the oilfield. Their studies also emphasised the benefits that resulted from applying best practices in energy management (e.g. gas turbine operation near design load, reduction of flaring and venting practices, and integration of waste heat recovery). Similarly, Kloster [4,5] argued that these measures could and did contribute to significant energy savings and a reduction of the CO_2-emissions of the Norwegian oil and gas installations. A mapping of the thermodynamic inefficiencies is useful, as it indicates rooms for improvements in a rational manner. Such information can be obtained by carrying out an exergetic analysis, which is based on both the 1st and 2nd laws of thermodynamics. The exergy of a system is defined as the maximum theoretical ability to do work in interaction with the environment, and is, unlike energy, not conserved in real processes [6,7]. An exergy accounting reveals the locations and extents of thermodynamic irreversibilities present in a given system and these irreversibilities account for a greater fuel use throughout successive processes [8].

Oliveira and Van Hombeeck [9] conducted an exergy analysis of a Brazilian oil platform which included the separation, compression and pumping modules but not the production manifolds. Their work showed that the least exergy-efficient subsystem was the oil and gas separation, while the most exergy-consuming ones were the petroleum heating and the gas compression processes. Voldsund et al. [10] carried out an exergy analysis of a Norwegian oil platform and considered the production manifold, the separation and recompression processes, the fuel gas subsystem and the oil pumping and gas reinjection trains. Their study demonstrated that the largest exergy destruction took place in the production manifold and in the gas reinjection systems. There was no considerable petroleum heating operations on this platform, since the feed temperature was high enough for separation of the specific oil by pressure reduction only: there was therefore no exergy destruction due to heating operations. Nguyen et al. [11] conducted a generic analysis of Norwegian oil and gas facilities. Their work suggested that the production manifold and gas compression trains were generally the most exergy-destructive parts, followed by the recompression and separation modules. It was also shown that these results were particularly sensitive to the compressor and pump efficiencies, as well as to the petroleum composition.

The similitudes and discrepancies in the results of these studies suggest that differences in the design setup and in the field conditions may affect the locations and extents of the thermodynamic irreversibilities of the overall system. The literature appears to contain no systematic comparison of the sources of exergy destruction for oil and gas platforms. Therefore, in this work, the platform analysed by Voldsund et al. [10] is compared with three other North Sea offshore platforms, which have not been studied in this manner before. The work was carried out in three main steps:

- simulation and investigation of the platforms;
- exergy accounting and analysis;
- comparison of the four platforms, based on the outcomes from the two previous steps.

The present paper is part of two larger projects dealing with modelling and analysis of oil and gas producing platforms. It builds on previous works conducted by the same authors and is structured as follows. *Section 2* describes the methodology followed in this work, with a strong emphasis on the system description and on the similarities and differences between the four cases. *Section 3* presents a comparison of the results obtained for each platform. Explanations and discussions are detailed in *Section 4* and are followed by concluding remarks in *Section 5*.

2. Methodology

2.1. System description

The structural designs of the oil and gas processing at the four platforms are similar. Meanwhile, different reservoir fluid characteristics and reservoir properties as well as different requirements for the products, have led to dissimilar temperatures, pressures and flow rates throughout the process, and different demands for compression, heating, cooling and dehydration.

In Section 2.1.1 we give a generalised overview of the oil and gas processing system for the studied platforms, in Section 2.1.2 we present key information on the platforms, to indicate the main differences between them, and in Section 2.1.3 we list process data that are important to explain the varying results for the platforms. The appendix contains detailed process flowsheets for the four platforms, see Figs. A.1 – A.4.

2.1.1. A generalised overview of the processing system

A generalised overview of the oil and gas processing at the four platforms is shown schematically in Fig. 1. Well fluids from several producing wells (1) enter one or more production manifolds where pressure is reduced and streams from the different wells are mixed. The mixed streams (2) are sent to a separation train where oil, gas and water are separated in several stages by reducing pressure. Heating may be required in the separation process.

Oil or condensate (3) is sent to the main oil/condensate treatment section where it is pumped for further export (4). Produced gas is compressed in a recompression train to match the pressure of the stream entering the separation train (2). This compression is done in several stages, each stage with a cooler, a scrubber and a compressor. Condensate from the recompression train is sent back to the separation train, while compressed gas is sent to the gas treatment section.

The produced gas is treated differently on the four platforms, with different demands for compression and dehydration, depending on the properties of the gas and on whether the product (5) is to be exported or used for enhanced oil recovery (injection or gas lift). On one of the platforms additional gas is imported (10) and compressed in this section. Condensate from the gas treatment is either recycled to the separation train or pumped, dehydrated and exported (6) in a separate condensate treatment section. Fuel gas is taken from one of the streams with produced gas, treated in a fuel gas system and sent (9) to the power turbines, and for two of the platforms also to the flares for pilot flames.

Produced water is treated and either discharged to the sea (7) or injected into another reservoir (8). Seawater (11) may be compressed for injection into the reservoir for enhanced recovery (12).

2.1.2. Key information on the studied platforms

The studied platforms are labelled Platform A, B, C and D, and main characteristics for each of them are given below:

- Platform A has been in production for approximately 20 years and is characterised by a high gas-to-oil ratio. Oil is pumped to a nearby platform while gas is injected into the reservoir for pressure maintenance. Water injection is also used as a recovery technique, but the injection water is produced at another platform, and is therefore not taken into consideration in this analysis. Produced water is discharged to the sea. Platform A was investigated in previous works from the same authors and more details of the analysis can be found in [10].
- Platform B has been in production for approximately 10 years. It has high reservoir temperature, pressure and gas-to-oil ratio and produces gas and condensate through pressure depletion. The exported gas is not dehydrated. Produced water is injected into another reservoir for disposal.

Power consumption is small because of a relatively low compression demand. There is some heat integration between process streams with cooling- and heating demand.

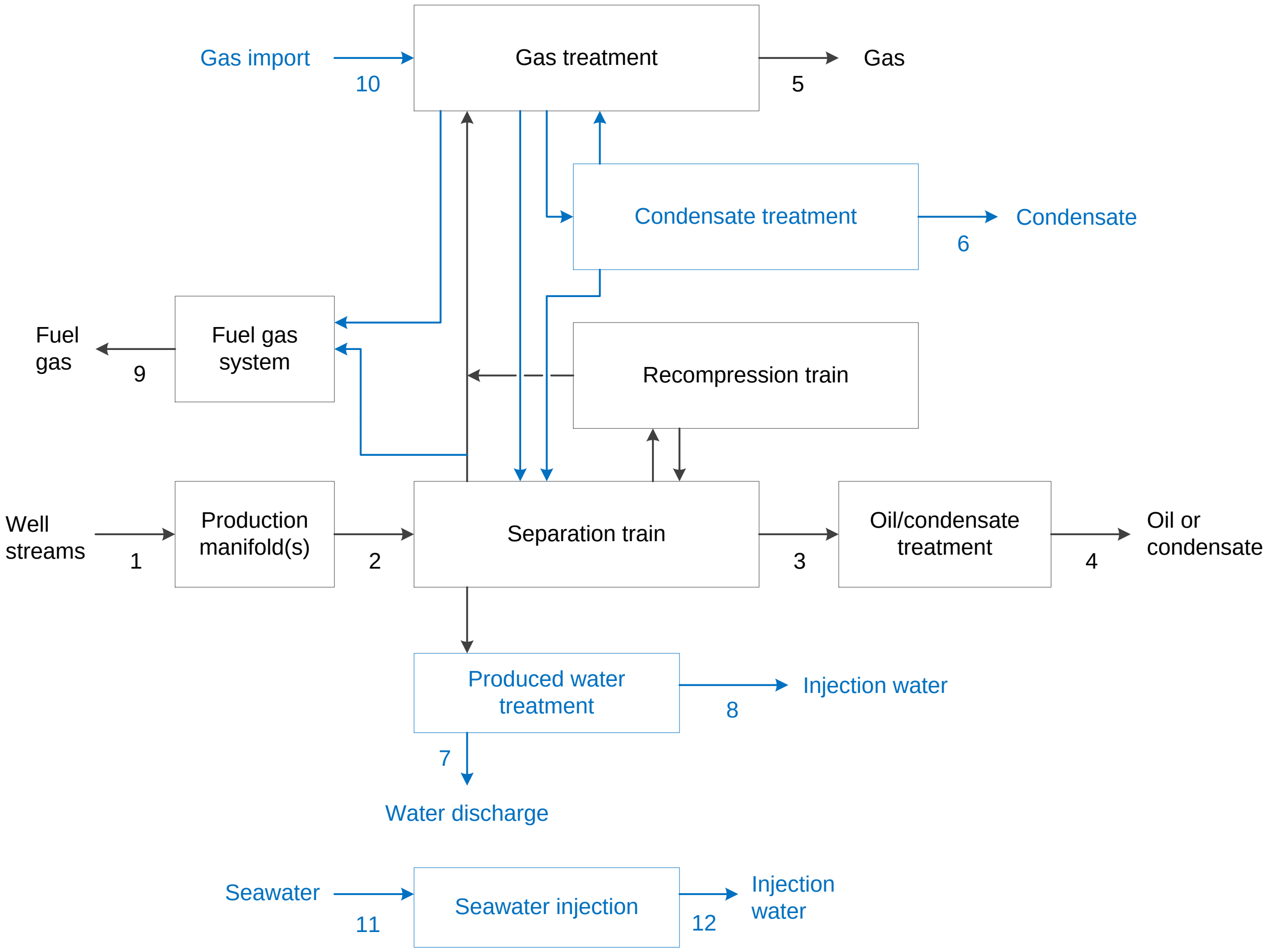

Fig. 1. A generalised overview of the oil and gas processing on a North Sea platform. The arrows represent one or several mass streams while the blocks represent subsystems. Black arrows and blocks are the same for all the studied platforms. Blue arrows and blocks are not present at all four platforms.

- Platform C has also been in production for approximately 10 years. It produces oil with high viscosity, and heating is required for the crude oil-water separation. The heating demand is met by waste heat recovery from the exhaust gases exiting the gas turbines, and by heat integration with other process streams. Gas lifting is used in order to decrease the density of the oil and enhance recovery, and gas is also injected into the reservoir for pressure maintenance. Due to the low gas-to-oil ratio, gas is imported for injection and gas lifting purposes. Produced water is discharged to the sea.
- Platform D has been in production for approximately 20 years, and gas, oil and condensate is exported. The treatment and export of condensate is due to a high propane content in the reservoir fluid, and is done to prevent recirculation of medium-weight alkanes in the recompression train and extra power consumption. Both gas and condensate are dehydrated. Heating is required to enhance separation of oil, gas and water, and for regenerating the glycol used for dehydration. Gas lifting and water injection is used to enhance oil recovery.

The gas-to-oil ratios and product flow rates for each of the studied platforms are given in Table 1.

Table 1. Gas-to-oil ratios and product flow rates for the studied oil and gas platforms. Gas-to-oil ratio is given on a standard volume basis, with a standard temperature of 15°C and pressure of 1.013 bar.

	Platform A	Platform B	Platform C	Platform D
Gas-to-oil ratio, -	2800	3200	350	260
Exported oil, Sm^3/h	133	-	1094	195
Exported condensate, Sm^3/h	-	239	-	7.6
Exported gas, 10^3 Sm^3/h	-	761	-	7.2
Injected gas, 10^3 Sm^3/h	369	-	362	-
Lift gas, 10^3 Sm^3/h	-	-	22	45.2
Produced water, Sm^3/h	67	18	8	1332
Injected water, Sm^3/h	-	-	-	919

2.1.3. Process details

Temperatures and pressures for key streams are given in Table 2. The following points are essential for the outcome of the analysis:

- Pressure is reduced in the production manifold and the separation train. Well stream pressures, P_1, and pressures into the separation train, P_2, vary between the platforms, while pressure out of the separation train, P_3, is between 1.7 and 2.8 bar for all platforms, due to vapor pressure requirements for the oil/condensate export.
- Heating is required in the separation train on Platform C, even if the separation train inlet temperature, T_2, is almost as high as on Platform A. This is in order to avoid problems with emulsions and to enhance separation between oil and water, which might be problematic due to the high viscosity of the crude.
- In the export pumping section the pressure of the produced oil or condensate is increased from P_3 to P_4. The magnitude of P_4 depends on the export pipeline requirements.
- The gas treatment section varies between the platforms, depending on the conditions of the incoming gas, and the planned use of it. On Platforms A, C and D the pressure is increased from P_2 to P_5, since the produced gas is to be injected, used for gas lifting or exported at a pressure higher than P_2. On Platform B the gas is not compressed. Since the well-stream pressure is high, they can allow a pressure at the outlet of the production manifold higher than the pressure required for export, so P_5 is lower than P_2. For a detailed overview of the structural design of this section in each of the platforms, we refer to Figs. A.1 – A.4.
- The imported gas on Platform C is compressed from P_{10} to P_5 in the gas treatment section.
- The produced water on Platforms B and C is compressed from P_7 to the injection pressure, P_8, while on platform D the seawater is compressed from P_{11} (ambient) to P_{12} and injected.

Table 2. Pressures and temperatures in the oil- and gas processing of the studied oil and gas platforms.

Stream number (type)	Platform A p (bar)	Platform A T (°C)	Platform B p (bar)	Platform B T (°C)	Platform C p (bar)	Platform C T (°C)	Platform D p (bar)	Platform D T (°C)
1 (reservoir fluids)	88 – 165	80 – 87	122 – 155	64 – 111	13 – 110	51 – 73	15 – 187	55 – 74
2 (reservoir fluids)	70	74	120	106	46[a)] 8[b)] 14[c)]	61[a)] 66[b)] 60[c)]	8	49 –67 63[c)]
3 (oil/condensate)	2.8	55	2.4	63	2.7	96	1.7	45 – 55
4 (oil/condensate)	32	50	107	56	99	76	50	61 – 68
5 (treated gas)	236	78	118	35	184	75	179	81
6 (condensate)	-	-	-	-	-	-	179	68
7 (produced water)	9	73	-	-			1.3	55
8 (produced water)	-	-	61	80	7.2	62	127-147	57
9 (fuel gas)	18	54	37	50	-	-	-	-
10 (gas import)	-	-	-	-	110	4.4	-	-
11 (seawater)	-	-	-	-	-	-	1.0	8
12 (seawater)	-	-	-	-	-	-	127 – 147	57

a) From high pressure manifold

b) From low pressure manifold

c) From test manifold

Since flow rates throughout the process change over the field lifetime, some parts will be run at other flow rates than the process equipment was designed for. To avoid compressor surging in this situation, gas is recycled around the compression stages, to keep a minimum flow rate through the compressor. The recycled gas is also sent through the cooler and the scrubber of the compression stage, to keep a low temperature and to avoid liquid in the compressor. The gas recycling rates around compressor stages in the various compression sections of the four platforms are given in Table 3. There is anti-surge recycling in the recompression trains of all the platforms, while in the gas treatment section there is recycling of the imported gas in Platform B and of the produced gas in Platform D.

Table 3. Anti-surge recycle rates in the various compression sections of the studied oil and gas platforms, given as percentage of the flow through the compressors.

	Platform A	Platform B	Platform C	Platform D
Recompression train	69 – 92%	4 – 33%	19 – 40 %	65 – 75%
Gas treatment, produced gas compression	0%	-	0%	5 – 35%
Gas treatment, import gas compression	-	-	23%	-

2.2. Process simulation

The process simulations of Platforms A and C were carried out with Aspen HYSYS® version 7.3 [12] using the Peng-Robinson equation of state [13], while for Platform B the same software was used, but with the Soave-Redlich-Kwong equation of state [14]. The water purification processes were neglected for Platforms A-C. Platform D was simulated with Aspen Plus® version 7.2 [15] using the Peng-Robinson equation of state and the Non-Random Two Liquid model [16], with the exception of the glycol dehydration system that was simulated using the glycol property package of Aspen HYSYS® [12]. The water purification and injection processes of Platform D were simulated based on the Non-Random Two Liquid model and the dehydration process on the glycol property package of Aspen HYSYS® [12].

The test manifold was merged together with the 1st stage separator in the simulations of Platforms A and B, while it was included as an independent separator in the simulations of Platforms C and D.

The well fluids are complex mixtures of crude oil, gas and water, and in all cases these fluids were simulated using a mix of real chemical components such as water and methane, as well as hypothetical components that describe the heavier oil fractions.

2.3. Exergy analysis

Exergy analysis is a well-established field. However, to facilitate reading we repeat the equations essential to this study. For a thorough introduction to exergy analysis, see for instance the textbook of Kotas [6].

2.3.1 Exergy accounting

An exergy accounting was performed to identify the sources of thermodynamic inefficiencies in the four cases investigated. Internal irreversibilities within the oil and gas processing units are responsible for entropy generation and thus exergy destruction, and can be calculated from an exergy balance [8].

For an open control volume in steady-state conditions, the exergy destruction rate, $\dot{E}_d$, is defined as the difference between the rates of exergy entering a system, $\dot{E}_{in}$, and of exergy leaving it, $\dot{E}_{out}$:

$$\dot{E}_d = \sum \dot{E}_{in} - \sum \dot{E}_{out} = \dot{E}_W + \dot{E}_Q + \sum_j \dot{m}_j e_j, \qquad (1)$$

where $\dot{E}_W$ and $\dot{E}_Q$ are the rates of exergy accompanying work and heat, respectively. For simplicity we name these variables power and heat exergy in the rest of this study. The symbols $\dot{m}_j$ and e_j represent the mass flow rate and the specific exergy of the stream of matter j. The exergy balance can also be expressed as [17]:

$$\dot{E}_p = \dot{E}_u - \dot{E}_d - \dot{E}_l, \qquad (2)$$

where:

- $\dot{E}_p$ is the rate of product exergy, which corresponds to the desired output of the system;
- $\dot{E}_u$ is the rate of utilised or fuel exergy, representing the resources needed to drive the system;
- $\dot{E}_l$ is the rate of exergy losses, which is associated with the transport of exergy to the surroundings with energy and material streams (external irreversibilities).

2.3.2 Exergy transfer

The exergy transported with a stream of matter, e, can be expressed as the sum of its kinetic, e^{kin}, potential, e^{pot}, physical, e^{ph}, and chemical components, e^{ch} [8]:

$$e = e^{kin} + e^{pot} + e^{ph} + e^{ch}. \qquad (3)$$

The specific physical exergy accounts for differences in temperature and pressure in reference to the ambient conditions (T_0, p_0) without changes in chemical composition. It is defined as:

$$e^{ph} = (h - h_0) - T_0(s - s_0), \qquad (4)$$

where h and s are the specific enthalpy and entropy calculated at the stream conditions and h_0 and s_0 at ambient temperature, T_0, and pressure, p_0. The specific chemical exergy accounts for differences in chemical composition with a reference environment and can be expressed, on a mass basis, as:

$$e^{ch} = \underbrace{\sum_i x_i \overline{e_i}}_{\mathrm{I}} + \underbrace{\left[\left(h_0 - \sum_i x_i h_{i,0}\right) - T_0\left(s_0 - \sum_i x_i s_{i,0}\right)\right]}_{\mathrm{II}} = \underbrace{\sum_i x_i \overline{\overline{e_i}}}_{\mathrm{III}} \qquad (5)$$

where the term I represents the chemical exergy of the pure components, with x_i the mass fraction and $\overline{e_i}$ the specific chemical exergy. The term II corresponds to the decrease of chemical exergy due to mixing effects, with $h_{i,0}$ the chemical enthalpy of the pure component i at ambient conditions, and $s_{i,0}$ the corresponding entropy. The term III denotes the chemical exergy of the components in the mixture, with $\bar{\bar{e}}_i$ the specific chemical exergy of the component *i* in the mixture. The specific potential and kinetic exergies are equal to the potential and kinetic energies, respectively.

2.3.3. Calculation details

The ambient temperature and pressure used in the calculation of physical exergy and the mixing part of the chemical exergy were 8°C and 1 atm. The chemical exergy of the pure components were taken as presented by Kotas [6] for the real chemical components and calculated following the method of Rivero [18] for the hypothetical components. Potential and kinetic exergy were assumed negligible in comparison with chemical and physical exergy in the present cases.

3. Results

The amounts of exergy exported from each of the platforms as oil, condensate or gas, together with the consumption of exergy in form of heat and power are given in Table 4. The chemical exergy in the oil and gas that passes through the system is very high compared to the exergy changes within the system. The consumption of power and heat exergy is less than 2% of the exergy exported for all the platforms.

Table 4. Exergy exported, and power- and heat exergy consumed on the studied platforms.

		Platform A	Platform B	Platform C	Platform D
Exergy exported	MW	1 400	11 000	12 600	2190
Power exergy consumption	MW	24.6	5.5	29.8	23.3
Heat exergy consumption	MW	0	0.3	4.7	0.9

The power and heat exergy, which are consumed in each subsystem for the four platforms, are presented in absolute numbers and per oil equivalent in Fig. 2 and Fig. 3, respectively. It is shown that:

- Power is mainly used for compression in the recompression sections, gas treatment sections and oil/condensate sections.
- On Platform D a significant amount of power is also used for compression in the water injection system.
- No power is required in the gas treatment section on Platform B, at the difference of the three other platforms, because the feed pressure (P_1) at the inlet of the separation subsystem is high enough to meet the export specifications (P_5).
- In the separation section on Platform C, about a third of the exergy used for crude oil heating comes from heat integration with other product streams, while the remaining two thirds come from waste heat from the power turbines.
- The heating demand of the gas treatment and oil/condensate treatment sections on Platform D (in the dehydration processes) is met by recovering waste heat from the power turbines and to a minor extent by heat integration.
- Power used for heating in the fuel gas systems and for compression in produced water handling is negligible compared to the exergy consumption in other subsystems.
- Power and heat exergy consumed per oil equivalent is highest for Platform A, followed by Platform D, while it is relatively small for Platforms B and C.

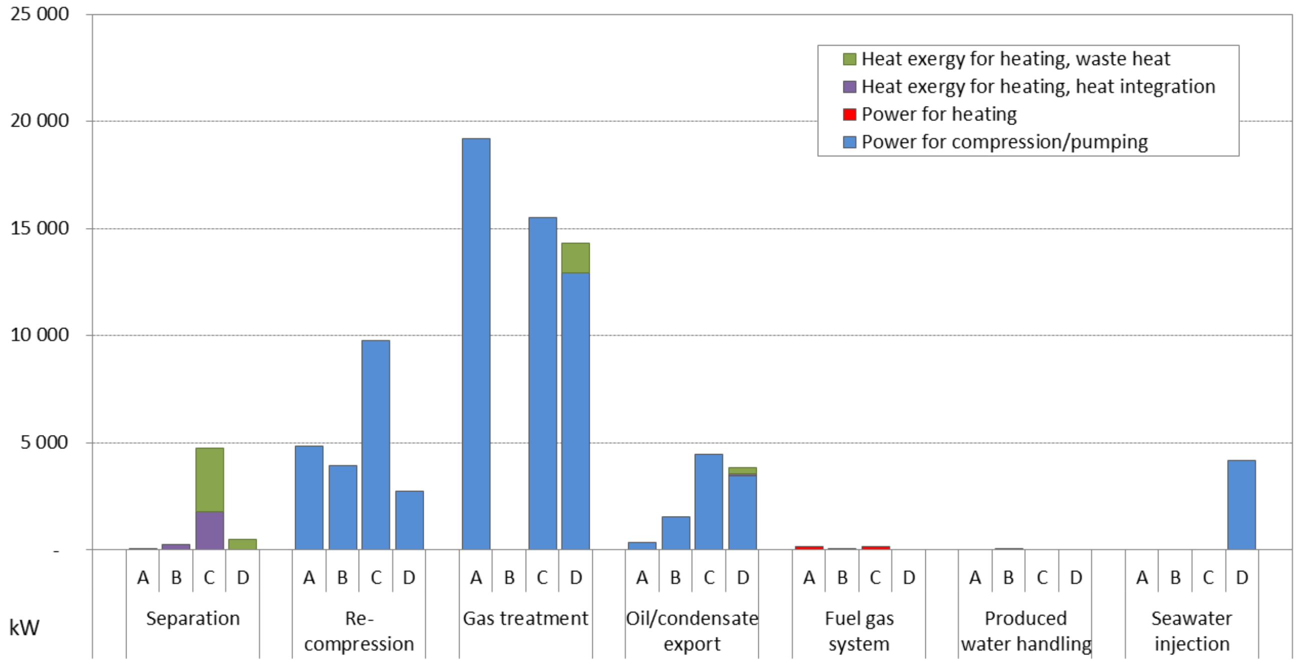

Fig. 2. Power and heat exergy consumed in each subsystem for the studied platforms (Platforms A - D). The production manifolds are not included, since no power and heat exergy is consumed there. The thermal energy labelled 'waste heat' is from a heating medium that is heated with waste heat from the power turbines. The thermal energy labelled 'heat integration' is from heat integration with other process streams.

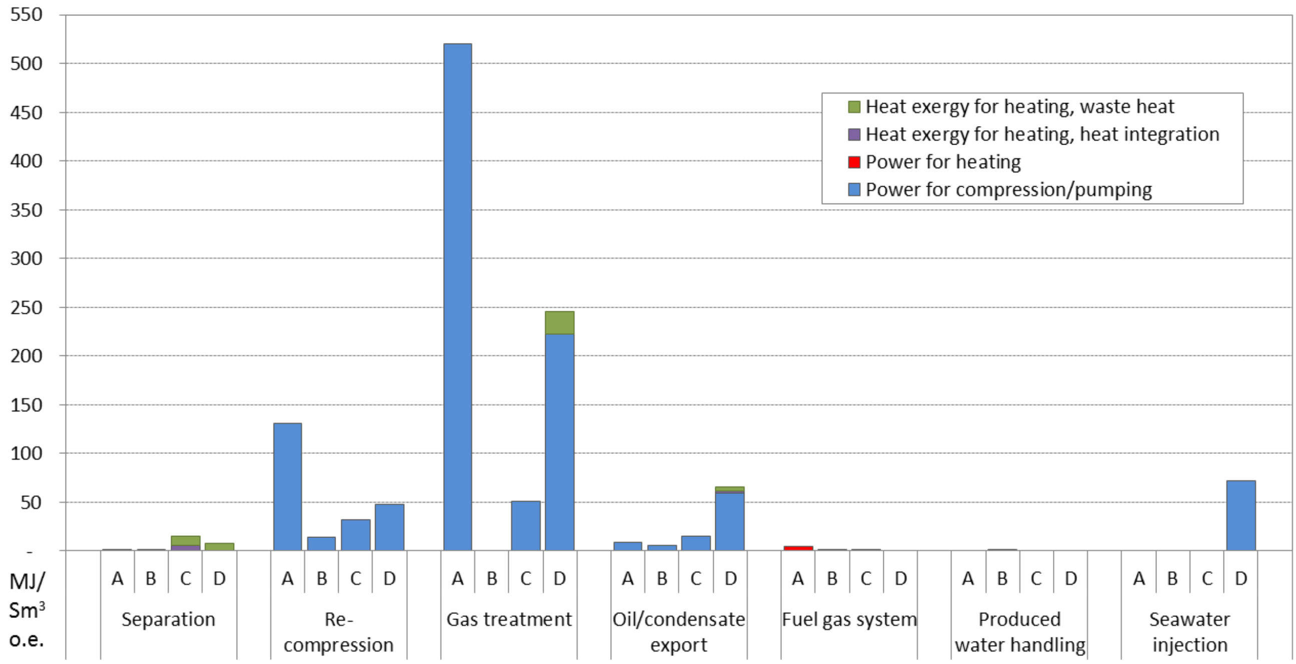

Fig. 3. Power and heat exergy consumed per exported oil equivalent (o.e.) in each subsystem for the studied platforms (Platforms A - D). The production manifolds are not included, since no power and heat exergy is consumed there. The thermal energy labelled 'waste heat' is from a heating medium that is heated with waste heat from the power turbines. The thermal energy labelled 'heat integration' is from heat integration with other process streams. The following conversion factors are used when converting to o.e: 1 Sm^3 oil = 1 Sm^3 condensate = 1000 Sm^3 gas = 1 Sm^3 o.e.

In Fig. 4 exergy destruction and exergy lost with cooling water in each subsystem for each of the platforms are given and in Fig. 5 the same values are given as percentage for each platform. In general, the highest contributions to exergy destruction and exergy losses are due to:

- throttling in production manifolds and separation trains;
- irreversibilities in coolers and losses with cooling medium;
- inefficiencies in compressors and anti-surge recycling.

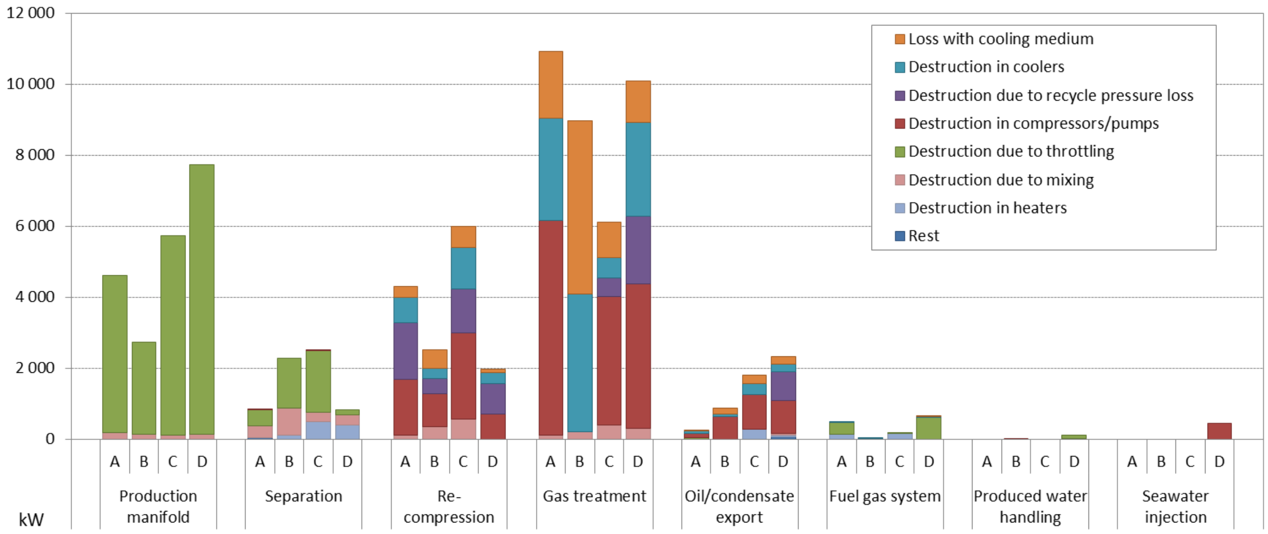

Fig. 4. Exergy destruction and loss in each subsystem for the studied platforms (Platforms A – D). The main sources of exergy destruction/loss in each subsystem are indicated with different colours, and smaller sources are lumped into 'rest'.

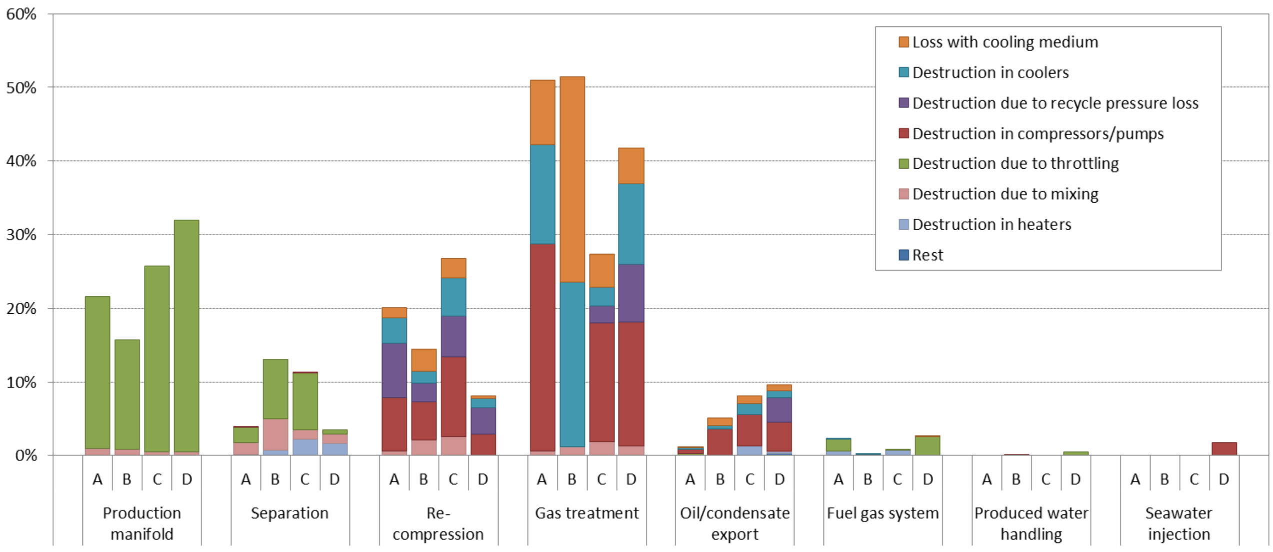

Fig. 5. Percentage of exergy destruction and loss in each subsystem for the studied platforms (Platforms A – D). The main sources of exergy destruction/loss in each subsystem are indicated with different colours, and smaller sources are lumped into 'rest'.

A more detailed investigation of Fig. 5 shows the following about the locations and sources of exergy destruction and losses on the four platforms:

- Exergy destruction in production manifolds represents 16–32% of the total exergy destruction at the four platforms.
- Exergy destruction due to throttling in separation trains accounts for 1–8%.
- Exergy destroyed in compressors amounts to 20–35%, with the exception of Platform B where it amounts to only 5%.
- On Platform B, 50% is due to cooling in the gas treatment section.
- Exergy destruction due to pressure loss in recycled streams amounts to 3–15% for the four platforms.
- Exergy destruction in the crude oil heater makes up approximately 2% for both Platforms C and D.
- The exergy destruction and losses in the oil/condensate export system of Platform A accounts for 1%, while for Platforms B – D it accounts for 5–10%.
- Exergy destruction and losses in the fuel gas, produced water handling and seawater injection systems are of minor importance compared to the other studied systems.

The exergy destroyed and lost per exported oil equivalent in each subsystem for the four platforms are shown in Fig. 6. Platforms A and D have clearly more inefficiencies per oil equivalent than Platforms B and C. They are older than the other two platforms and have export flow rates that are low compared to their peak production. Platform A has a high gas-to-oil ratio, injects gas and exports only oil. The injection of gas makes a high oil recovery from the reservoir possible but is responsible for considerable power consumption and exergy destruction:

- The high amount of gas that is not exported gives high exergy destruction per exported oil equivalent in the production manifold.
- In the recompression train, recycling of gas to prevent compressor surging has led to almost constant flow rates, and thus exergy destruction and losses, even if the amount of oil in the separation train has decreased.
- The high exergy destruction and loss per exported oil equivalent in the gas treatment section is because here a significant amount of compression work is done to produce gas that is not exported but used for enhanced oil recovery.

Platform D has a low gas-to-oil ratio, uses gas, produced water and seawater for lift and injection, and exports oil, gas and condensate. The high exergy destruction per exported oil equivalent results both from the large amount of power required to compress the gas and from the depressurisation of the reservoir fluid in the production manifold.

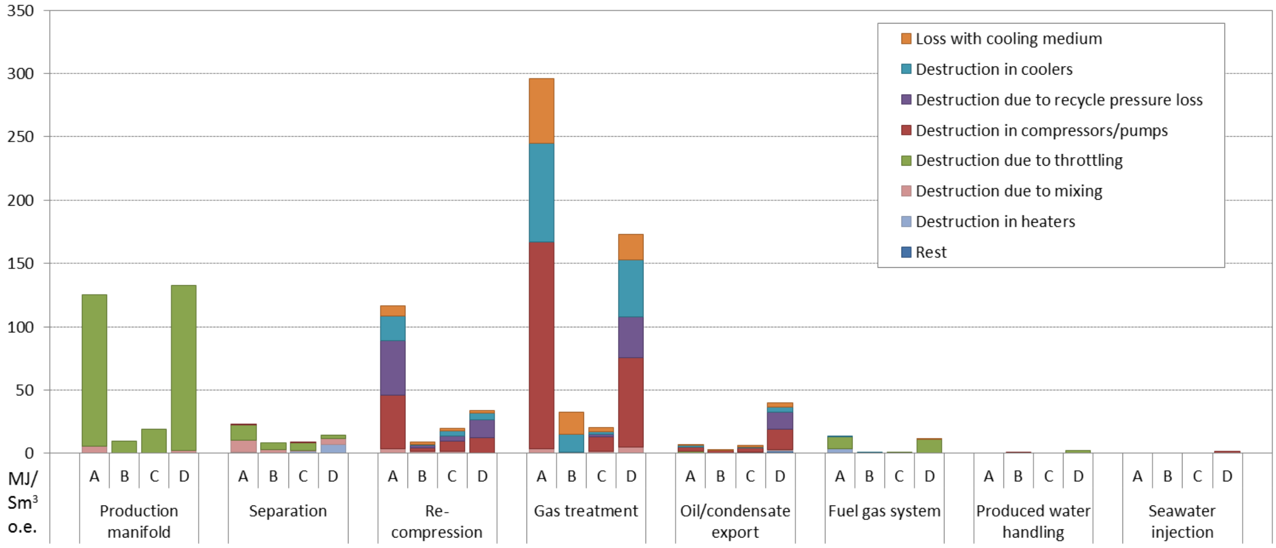

Fig. 6. Exergy destruction and loss per exported oil equivalent (o.e.) in each subsystem for the studied platforms (Platforms A-D). The main sources of exergy destruction/loss in each subsystem are indicated with different colours, and smaller sources are lumped into 'rest'.

4. Discussion

We have mapped exergy consumption and exergy destruction and losses in the oil and gas processing system of four oil and gas platforms. These results can be compared to the previous findings of Bothamley [19] and Svalheim [2,3]. They stressed the great power consumption associated with the gas treatment, recompression and oil pumping steps of various oil and gas facilities located in the North Sea region and in the Gulf of Mexico, which is confirmed by the present analysis. They also stressed the high power demand due to water injection, which was only significant on Platform D, as this is the only facility where it is implemented.

These authors [2,3,19] also suggested several efficiency measures, such as the re-wheeling of the turbo-machinery components, to reduce the power consumption of the processing plant. The same was suggested after the exergy analysis of Platform A [10] and of a generic platform simulation [11]. These studies, together with the present results, indicate the importance of gas compression subsystems when monitoring oil and gas facilities and trying to improve their performance. In the two latter references, production manifolds were also pointed out as sections with high losses, and ways to reduce these losses are discussed.

Oliveira and Van Hombeeck [9] investigated a real-case oil facility located in Brazil. The gas delivery pressure was about 174 bar, which is similar to the pressure requirements of the gas produced on the Platforms A, B and D. In these four cases, the gas treatment step ranks as one of the most exergy-consuming subsystems. This suggests that improvement measures could well focus on this particular part of the processing system and on the subsystems interacting with it. However, they also emphasised the large exergy consumption of the heating operations taking place within the separation system, which was small or inexistent on the four platforms analysed in this work. For the two cases with some crude oil heating in this work, the heating demand was small enough to be covered by waste heat recovery from the exhaust gases exiting the gas turbines, and by heat integration with other process streams, while for the Brazilian case a furnace was required for crude oil heating in addition to a gas turbine heat recovery system. This discrepancy is mainly due to the differences in feed characteristics between the North Sea and the Brazilian Gulf regions. The temperature at the inlet of the separation was 7.4°C in their case, whilst it is between 45°C and 75°C for the four North Sea platforms described here. Seemingly, smaller systems such as the fuel gas, produced water and seawater injection systems contribute only to a minor extent to the total exergy destruction of the processing plant, which was also shown in their work.

Platform B had much lower power consumption per produced oil equivalent than the other three platforms in this study. The first separation stage takes place at a high pressure, avoiding the need for gas compression before export. Operating the first separation stage at as high pressure as possible reduces the exergy destruction in the production manifold, and the power consumption and exergy destruction in the gas treatment system. This illustrates that it is not sufficient to consider a single subsystem for improving the thermodynamic performance of the platform, but to also investigate the interactions and dependences between them.

The four platforms that are compared within this study are all of the North Sea platform type, and they represent some of the variety within this group of platforms, with production of heavy and viscous oil to condensate and gas, and different reservoir pressures and product specifications. The results common for these four platforms, such as high thermodynamic losses due to throttling in production manifolds and inefficient compression when feed conditions change over time, are therefore expected to be typical for a large part of the North Sea oil and gas platforms, which is supported by the findings in the generic analysis conducted by Nguyen et al. [11]. At the same time, the variations in power consumption and exergy destruction in the gas treatment section show the great differences that exist between North Sea platforms. The results depend strongly on factors such as (i) the efficiency and the control strategies of the turbo-machinery components (ii) the integration of additional subsystems such as condensate export and (iii) the outlet specifications of the processing plant. In addition, the differences between the platforms analysed in this study and the Brazilian case shows that caution should be exercised when extending the present conclusions to platforms in other regions of the world. Each oil platform should therefore be analysed individually, to pinpoint major sources of exergy destruction on that specific facility.

5. Conclusion

Exergy analyses were performed on the oil and gas processing systems on four North Sea oil and gas platforms, which differ by their operating conditions and strategies. The comparison of the exergy destruction sources illustrated the large exergy destruction associated with the gas treatment and production manifold systems, ranging above 27% and 16%, respectively. The fuel gas and seawater injection processes represent less than 3% each in every case.

However, the contributions of the recompression, separation and oil export sections vary significantly across the different platforms. Although the precise values of the exergy destruction rates differ from one platform to another, the main causes can be identified with the depressurisation in the production manifold, the compressor inefficiencies, and the heat transfers processes in the coolers.

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Appendix

This appendix contains process flowsheets for the four platforms, given in Figs. A.1–A.4. Details on process data for Platform A can be found in [10].

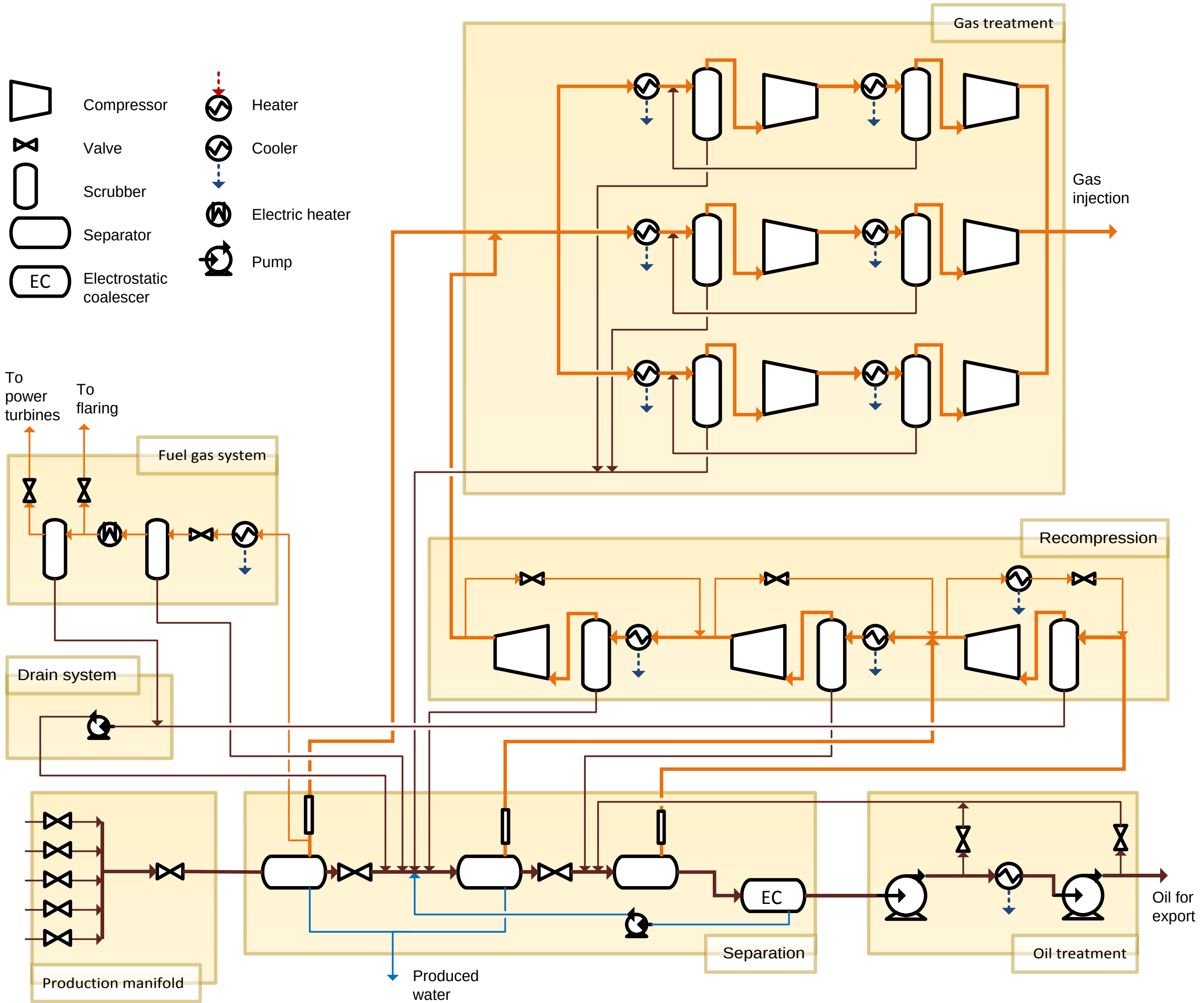

Fig. A.1. Process flowsheet of Platform A. Gas streams are shown with orange arrows, water streams with blue arrows, and oil, condensate and mixed streams are shown with brown arrows.

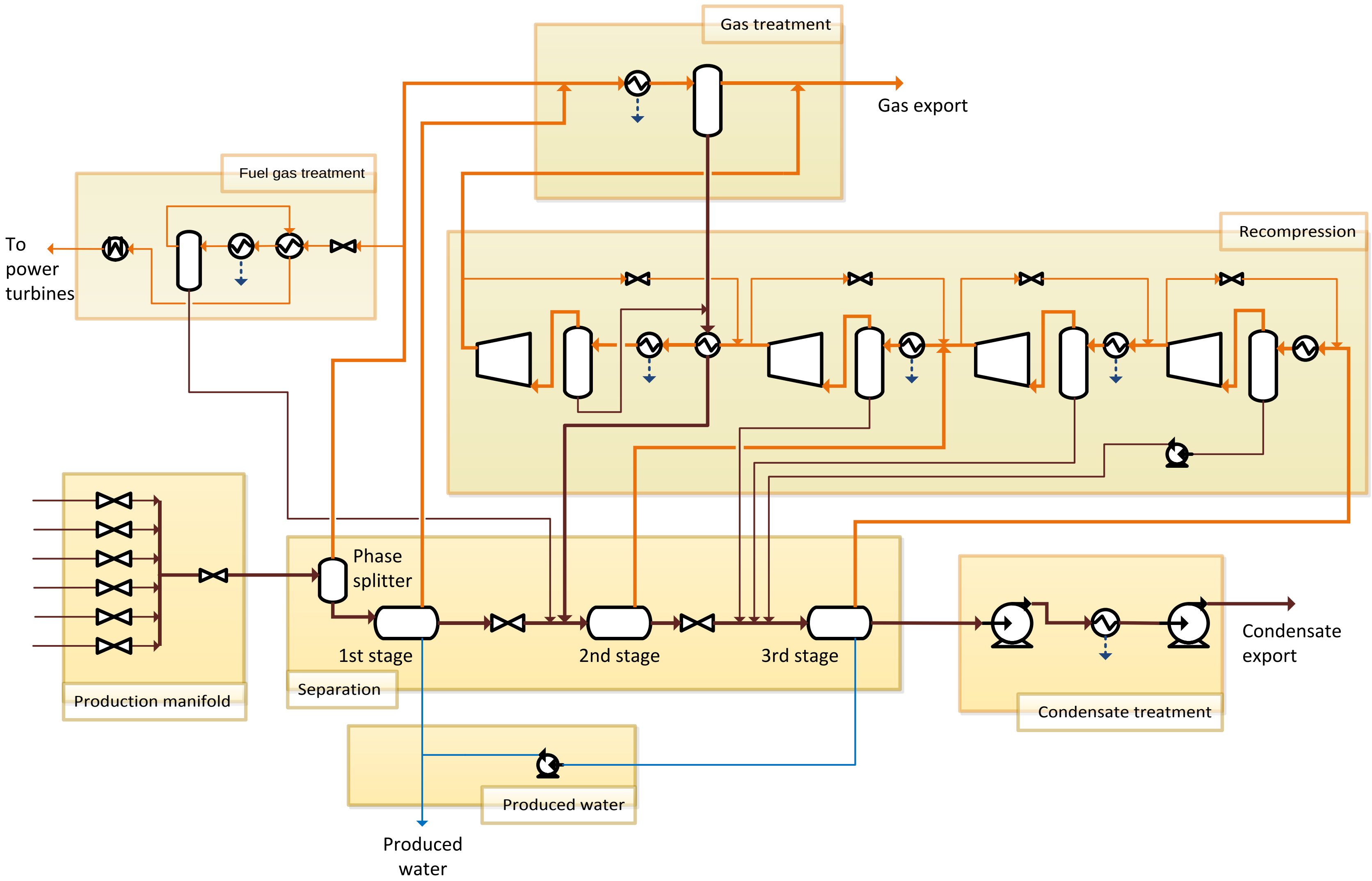

Fig. A.2. Process flowsheet of Platform B Gas streams are shown with orange arrows, water streams with blue arrows, and oil, condensate and mixed streams are shown with brown arrows. Symbol explanations can be found in Fig. A.1.

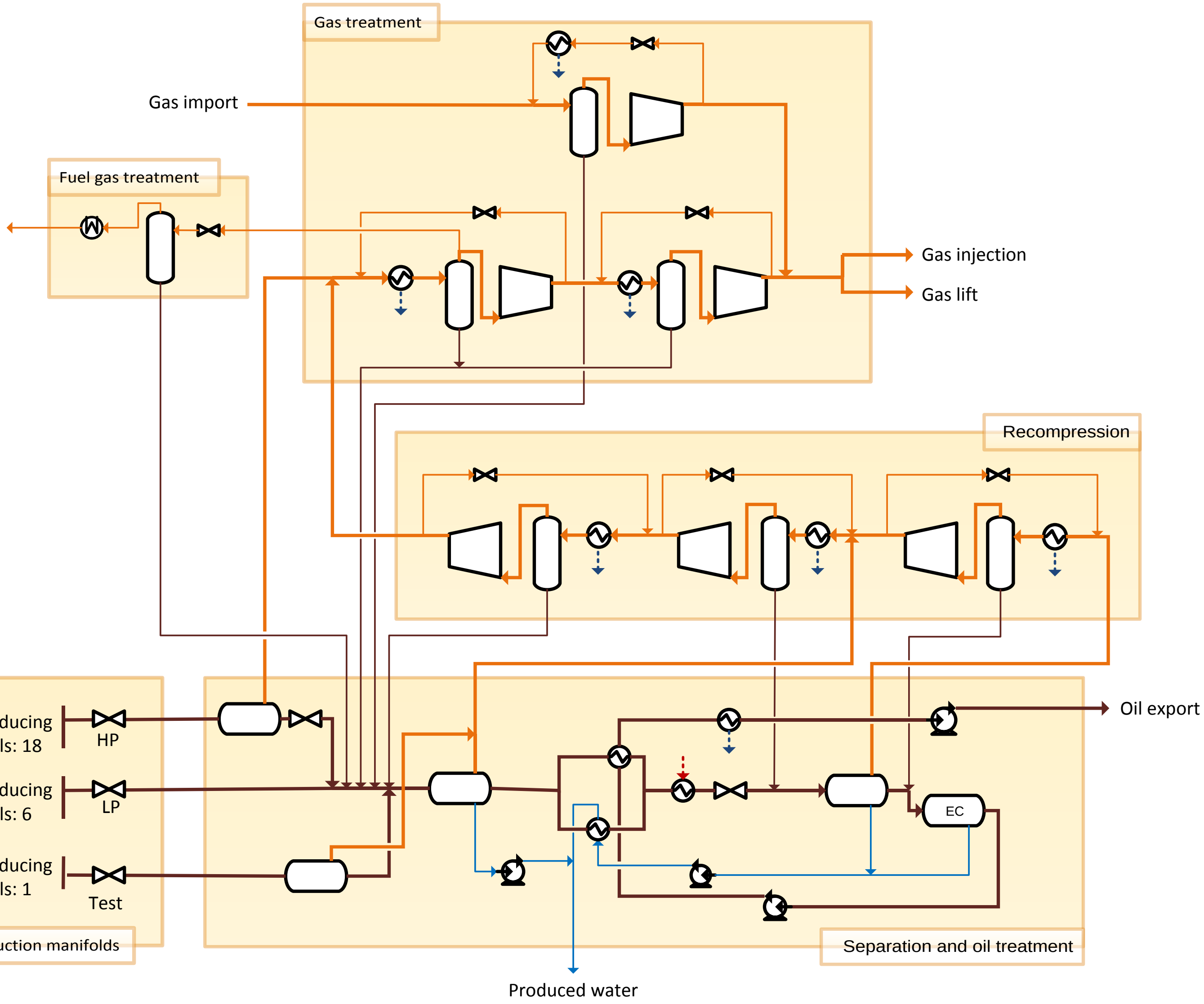

Fig. A.3. Process flowsheet of Platform C. Gas streams are shown with orange arrows, water streams with blue arrows, and oil, condensate and mixed streams are shown with brown arrows. Symbol explanations can be found in Fig. A.1.

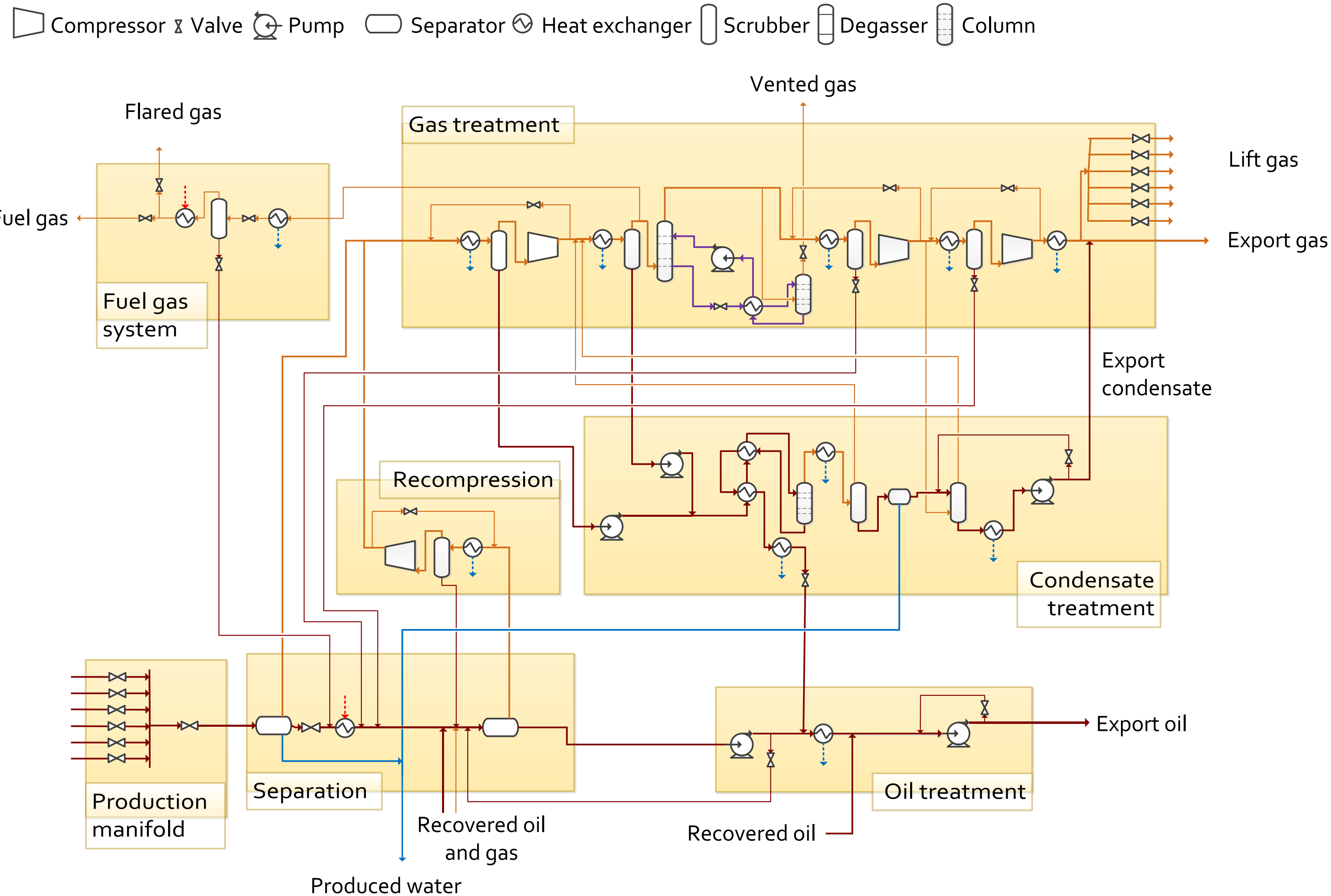

Fig. A.4. Process flowsheet of Platform D. Gas streams are shown with orange arrows, water streams with blue arrows, glycol is shown with purple arrows, and oil, condensate and mixed streams are shown with brown arrows.

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